

Environmental Perturbations Caused by the Impacts of Asteroids and Comets

Owen B. Toon, Kevin Zahnle, David Morrison
NASA Ames Research Center
Moffett Field, California

We review the major mechanisms proposed to cause extinctions at the Cretaceous-Tertiary geological boundary following an asteroid impact. We then discuss how the proposed extinction mechanisms may relate to the impact of asteroids or comets in general. We discuss the limitations of these mechanisms in terms of the spatial scale that may be affected, and the time scale over which the effects may last. Our goal is to provide relatively simple prescriptions for evaluating the importance of colliding objects having a range of energies, and compositions. We also identify the many uncertainties concerning the environmental effects of impacts. We conclude that, for impact energies below about 10^4 Mts (i.e. impact frequencies less than one in 6×10^4 years, corresponding to comets and asteroids with diameters smaller than about 400 m and 650 m respectively), blast damage, earthquakes and fires should be important on a scale of 10^4 or 10^5 km², which corresponds to the area damaged in many natural disasters of recent history. However, tsunami could be more damaging, flooding a kilometer of coastal plain over entire ocean basins. In the energy range of 10^4 to 10^5 Mts (intervals up to 3×10^5 yrs; comets and asteroids with sizes up to 800 m and 1.5 km respectively) water vapor injections and ozone loss become significant on the global scale. If the submicrometer dust injection fraction from the pulverized target material is much higher than is presently thought to be most likely, then dust injections could also be important in this energy range. This energy range is a conservative lower limit where damage might occur beyond the experience of human history. The energy range from 10^5 to 10^6 Mts (intervals up to 2×10^6 years; comets and asteroid up to 1.8 and 3 km diameter) is transitional between regional and global effects. The dust lifted in this energy range, the sulfur released from within impacting asteroids, and the soot from fires started by comets can produce climatologically significant global optical depths on the order of 10. Moreover, the ejecta plumes of these impacts may produce enough NO to destroy the ozone shield. Between 10^6 and 10^7 Mts (intervals up to 1.5×10^7 years; comet and asteroid diameters up to 4 and 6.5 km respectively) dust and sulfate levels would be high enough to reduce light levels below those necessary for photosynthesis. Ballistic ejecta reentering the atmosphere as shooting stars would set fires over regions exceeding 10^7 km², and the resulting smoke will reduce light levels even further. At energies beyond 10^7 Mts, blast and earthquake damage reach the regional scale (10^6 km²). Tsunami cresting to 100 m and flooding 20 km could sweep the coastal zones of

one of the world's ocean basins. Fires would be set globally. Light levels may drop so low from the smoke, dust and sulfate that vision is not possible. At energies approaching 10^9 Mts the ocean surface waters may be acidified globally by sulfur from the interiors of comets and asteroids. The Cretaceous-Tertiary impact in particular involved evaporite substrates that very likely generated a dense widespread sulfate aerosol layer with consequent climate effects. The combination of all of these physical effects would surely represent a devastating stress on the global biosphere.